Enhancement and Validation of a Model for Mine Scour and Burial

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LONG-TERM GOALS

Our long-term goal is to perfect a process-based model for the prediction of scour and burial of mines deployed in the shallow waters of the global coastal zone; and to use this model to develop general principles of mine burial that can be used by the fleet. We are presently pursuing this goal by expanding the physics and validation of the model to treat mine burial as a global problem using a hierarchy of interactive inputs (Figure 1). Systematic assignments for these inputs are developed according to coastal type.

OBJECTIVES

The basic scientific objective is to determine the appropriate geomorphic and hydrodynamic principles leading to:

• locally rapid mine burial

• time varying burial/exposure throughout the littoral cell

• identification of mine burial tendencies according to mine properties (size, shape, weight) and coastal type

To accomplish these objectives, we have upgraded model physics, expanded validation efforts using both archival and contemporary data sets, and performed sensitivity analyses to identify general mine burial principles (rules of thumb). When possible we apply these principles and related codes to benefit other Navy programs. These efforts have resulted in the development of a draft of a Mine Burial Primer for Fleet Use (Inman and Jenkins, 2002).

APPROACH

We have developed a Vortex Lattice Model (VORTEX) for mine burial prediction. VORTEX consists of two coupled models, each with distinct scale regimes: 1) nearfield burial involving length scales on the order of the size of the mine, and 2) farfield burial involving length scales of the order of the host littoral cell. The nearfield model uses vortex lattice computational techniques coupled to Bagnoldian sediment transport mechanics to predict burial by scour. Sediment budget formulations are used to predict burial by large-scale bottom elevation changes occurring over the farfield.

We have improved VORTEX by developing code for movable boundary conditions within the existing architecture. Movable boundary conditions in the nearfield account for mine migration by burial sequences involving scour and roll and scour and slip (Inman and Jenkins, 2002). Movable boundary conditions in the farfield involve seasonal equilibrium profile change and accretion/erosion waves from sediment flux associated with rivers and other sources. The code for the farfield boundary conditions is based on advection/diffusion solutions for the mass balance of a propagating accretion/erosion wave. The computational methodology is based on a series of boundary-conforming, coupled control cells having sufficient resolution to define coastline curvature and heterogeneity of sediment properties.

Ordering of site dependent inputs for VORTEX is attained through further development of a tectonic geomorphic coastal classification system (Inman and Nordstrom, 1971). The classification module in VORTEX selects the relative scaling for the littoral cell and associated control cells and assigns the sediment sources and sinks to which a particular burial site belongs. The classification includes three general tectonic types of coasts with their morphologic equivalents, and two types associated with latitudinal extremes: 1) collision coasts with narrow shelves and steep coastal topography resulting from collisions between two or more tectonic plates; 2) trailing-edge coasts that are on the stable, passive margins of continents with broad shelves and low inland relief; 3) marginal sea coasts that are semi-enclosed by island arcs and thereby fetch limited; 4) cryogenic coasts that are affected by ice processes; and, 5) biogenic coasts that are formed by fringing coral reefs or mangroves, etc.

The coastal classification system provides a pyramid of interactive inputs for mine burial prediction as shown in Figure 1. The essential types of information required for modeling mine burial form the five vertices of the pyramid. In the beginning of a prediction effort (top of the pyramid, $t = 0$), little information is available about the mines and mine lay area of concern, but more and more information becomes available as time increases, represented by the area of the expanding base of the pyramid with increasing time. The uncertainty associated with any one of these inputs at any given time will transpose to a certain degree of error in the processed-based prediction. The confidence of prediction could be evaluated by coupling VORTEX with an expert system model (ESM), providing an enriched ESM type of prediction. It is expected that the VORTEX process model will be coupled with an ESM in the near term of the Mine Burial Program.

Initial Evaluation
(t=0)

increasing information

a. ESM prediction

Mine type
5.

1. Coastal type

4. Sediment / bedform

2. Littoral cell

3. Forcing

time

ESM

input plane for process model

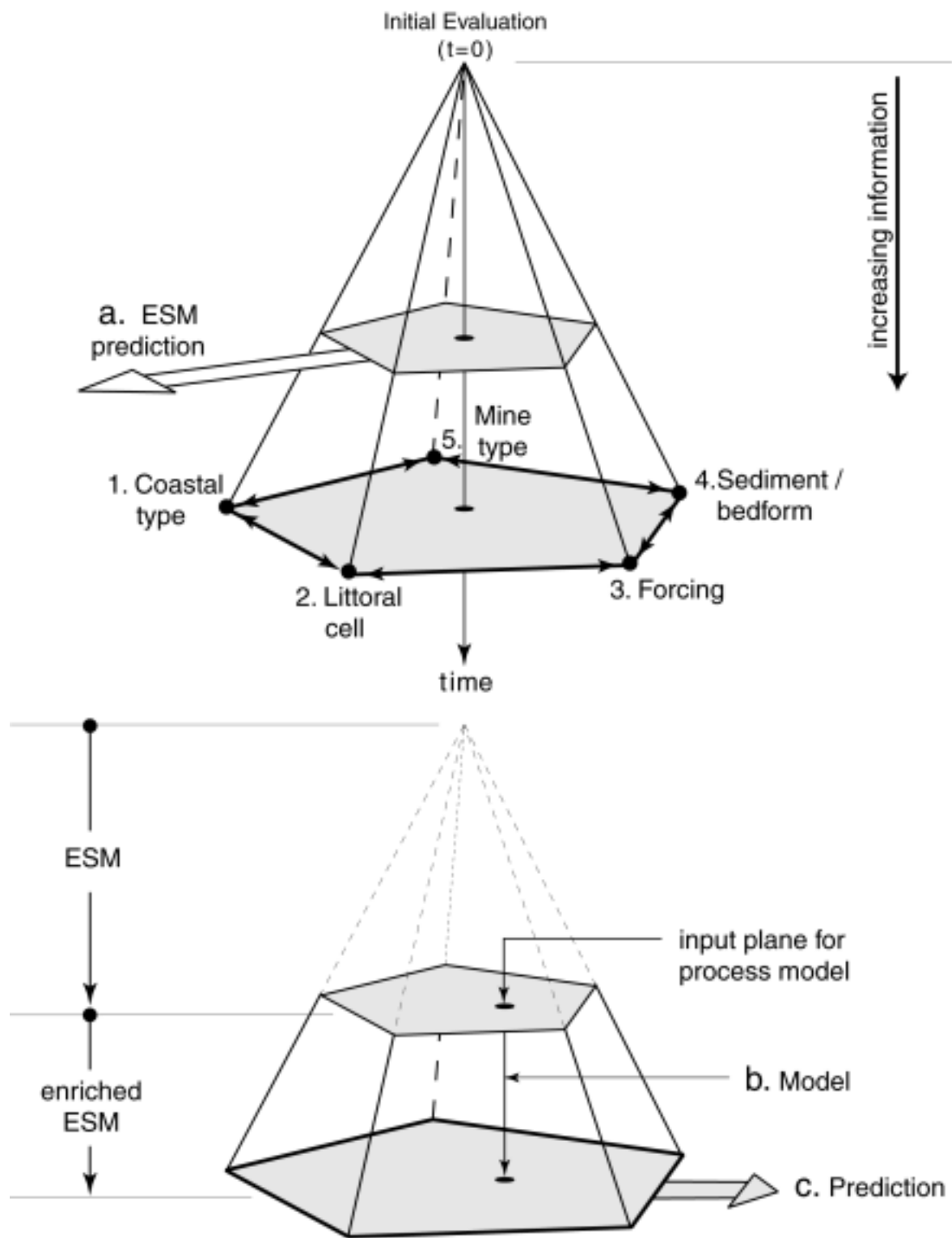enriched ESM

b. Model

c. Prediction

Figure 1. Hierarchy in the pyramid of interactive inputs for mine burial prediction using a combination of process and expert systems modeling (ESM). [from Inman and Jenkins, 2002a]

WORK COMPLETED

VORTEX has undergone coding and preliminary validation of the upgrades for movable boundary conditions. The model has been subjected to additional field testing during FY2001-02 off Scripps Pier, La Jolla, CA and off the Naval Amphibious Base, San Diego at Silver Strand Beach, CA in FY2002. The Scripps Pier experiments involved the MANTA mine and the MK VII VSW Marker, Type AFD. The Silver Strand Beach experiments were in conjunction with MK VII marine mammal exercises conducted by SPAWAR, Code D352. These experiments have been used to calibrate the model for the dependence of burial on forcing intensity and mine properties (size, weight, shape). Figure 2 shows a clear relation between the relative depth of scour and Strouhal number for mines placed in 7 meter deep water. The Strouhal number is defined as

$$St = \frac{u_m}{\sigma a} \approx \frac{d_o}{D} \qquad (1)$$

where u_m is the orbital velocity, d_o is the orbital diameter, σ is the wave radian frequency, a is the mine radius at the sand level and $D = 2a$ is the corresponding mine diameter. For 3-dimensional mine shapes such as a MANTA mine the maximum scour depth η_s has a power law dependence on Strouhal number (Figure 2),

$$\eta_s / a \sim St^{0.58} \qquad \text{(truncated cone)} \qquad (2)$$

Because flow disturbances are stronger for 2-dimensional bodies, scour depth for a cylindrical mine such as HM MARK 36 follows a higher power law dependence:

$$\eta_s / a \sim St^{0.71} \qquad \text{(cylinder)} \qquad (3)$$

Equations (2) and (3) indicate that scour depth is a greater percentage of the characteristic radius of a mine for a small mine than for a large mine. This follows from the fact that there is a greater degree of flow separation with stronger vortical scour when the orbital diameter of the fluid oscillation is large in comparison to the diameter of the object. Further validation of the model awaits field data from the Mine Burial Program. In the mean time, the present level of validation has led to the production of a Mine Burial Primer giving rules of thumb for burial and its variability among coastal type.

RESULTS

The new model codes with the hierarchy of interactive inputs (Figure 1) have been tested against both contemporary field experiments described in the previous section and archival databases (Dill, 1958; Donohue and Garrison, 1954; McMaster et al., 1955; Frazier and Miller, 1955; Salsman and Tolbert, 1962, 1966; Inman and Jenkins, 1996). These validation and sensitivity analyses have led to the following rules of thumb:

1) Cylindrical mines will bury by a scour and roll sequence, during which the axis of the cylinder will align itself parallel to wave crests. 2) The cylindrical mine may move a number of mine diameters in the direction of wave propagation during the burial sequence. 3) Scour holes formed by cylindrical
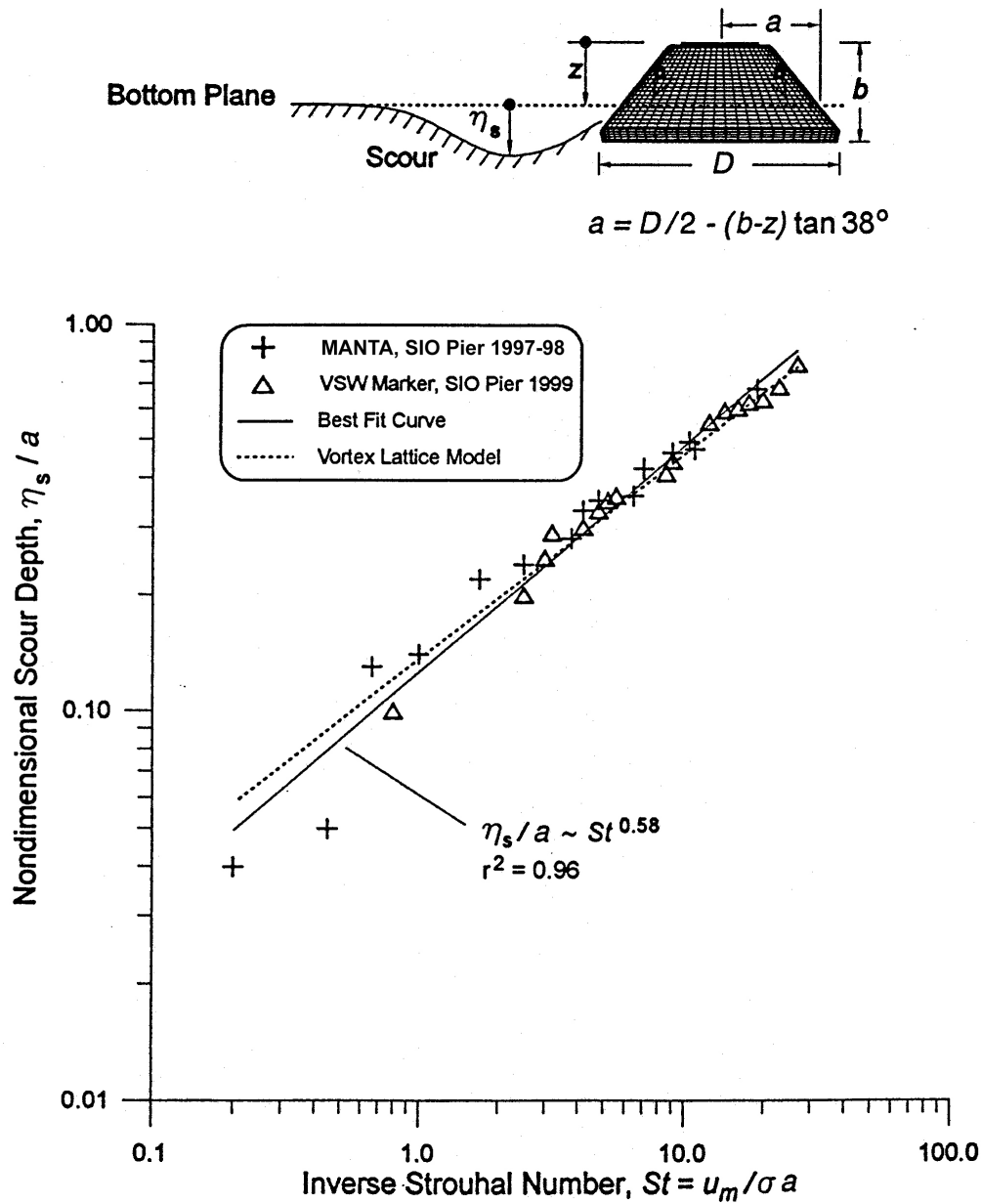
$$a = D/2 - (b-z)\tan 38°$$

In the graph:

$\eta_s/a \sim St^{0.58}$
$r^2 = 0.96$

Legend:
+ MANTA, SIO Pier 1997-98
△ VSW Marker, SIO Pier 1999
— Best Fit Curve
···· Vortex Lattice Model

Y-axis: Nondimensional Scour Depth, η_s/a
X-axis: Inverse Strouhal Number, $St = u_m/\sigma a$

Figure 2. Dependence of scour depth on Strouhal number St for a MANTA mine.
[from Inman and Jenkins, 2002a]

mines are deepest at the ends of the mine. During burial, cylindrical mines are buried more in the middle and become exposed at the ends. 4) Three-dimensional shapes (cones and hemispheres) bury more slowly than two-dimensional (cylindrical) shapes. 5) Small mines scour and bury deeper relative to their diameters than large mines, while absolute burial as measured from sediment surface to mine keel is greater for large mines. 6) Sour burial rates decrease as burial depth increases. This is because a partially buried mine presents a smaller silhouette to the flow. 7) Flat bottom mines (cones and hemispheres) will move less than 1diameter during a burial sequence. However, hemi-oblate

5

spheroids may flip over and move farther. 8) Burial rates due to scour by wave action are faster in the shallow water portion of the VSW zone. 9) Burial rates due to current action are usually faster in the offshore portion of the VSW zone (about 10-12 m depth) where coastal currents are more concentrated. However, longshore and rip currents may cause rapid burial and/or re-exposure in and near the surf zone (high tide to 3 m depth). 10) Impact burial is not a significant burial process in sandy environments (collision coasts, trailing edge coasts removed from river mouths, coral reef coasts). Impact burial is typically less than 10% in these environments. 11) Impact burial is the dominant burial process in muddy environments (deltaic marginal sea coasts and in estuaries and near river mouths of all coasts). Impact burial is typically 75% to more than 100% in these environments.

In general, burial rates of mines in the VSW zone will vary according to the characteristics that coastal type places on the hierarchy of interactive inputs (Figure 1). The input variables include the sediment grain size, bed roughness due to bedform, wave climate (energy flux and characteristic period), closure depth, and littoral cell dimensions. The mid-range for each of these variables was selected according to coastal type and used to initialize the free parameters of the VORTEX model in order to identify site dependent tendencies of burial.

The coastal type sensitivity analyses were done for 7 m depth (the mid-depth range of the VSW zone) using a cylindrical mine (MARK 52) and a truncated conical mine (MANTA). These two mine examples show the general difference in scour characteristics between a 2-dimensional shape (cylinder) and a 3-dimensional shape (truncated cone) of equivalent weight. Comparison of cylinders versus cones in Table 1 shows that the cylindrical shape buries faster than the truncated cone for all coastal types with the possible exception of the deltaic tideless marginal sea. In that case, burial is total for both shapes and is dominated by impact mechanics.

In general, marginal sea environments have the slowest burial rates for local waves of moderate height (less than 1.5 meters) because the short fetches produce shorter, less intense waves (Figure 3). Since high waves are generally rare along these marginal seas, the predictions in Figure 3 do not extend beyond 2 m heights. High-energy collision coasts have the highest burial rates following impact. This is due to the well-sorted fine sand typical for these coasts. Also, the narrow shelf and long wave periods of these high-energy coasts yield maximum onshore orbital velocities to induce scour. The burial rates along trailing edge coasts are similar to those on collision coasts, but the tendency for coarser sands along some of the former coasts lead to decreased rates. Similarly, the coarse carbonate sediments of the biogenic coasts also have lower burial rates than the collision coast in spite of similar wave climate.

A summary of burial rates over time periods ranging from days to several months is given in Table 1 for cylinder and truncated cone mine shapes. Both shapes show that burial is progressive over time but the rate tends to decrease with time as the mine silhouette decreases. The only exception to this rule of thumb occurs in the deltaic marginal sea where nearly all the burial occurs during impact. The results in Table 1 generalize the farfield burial by using long term mean values for forcing and littoral cell scales. Burial rates can be quite different if extreme events such as storms, river floods, landslides, or tsunamis occur.
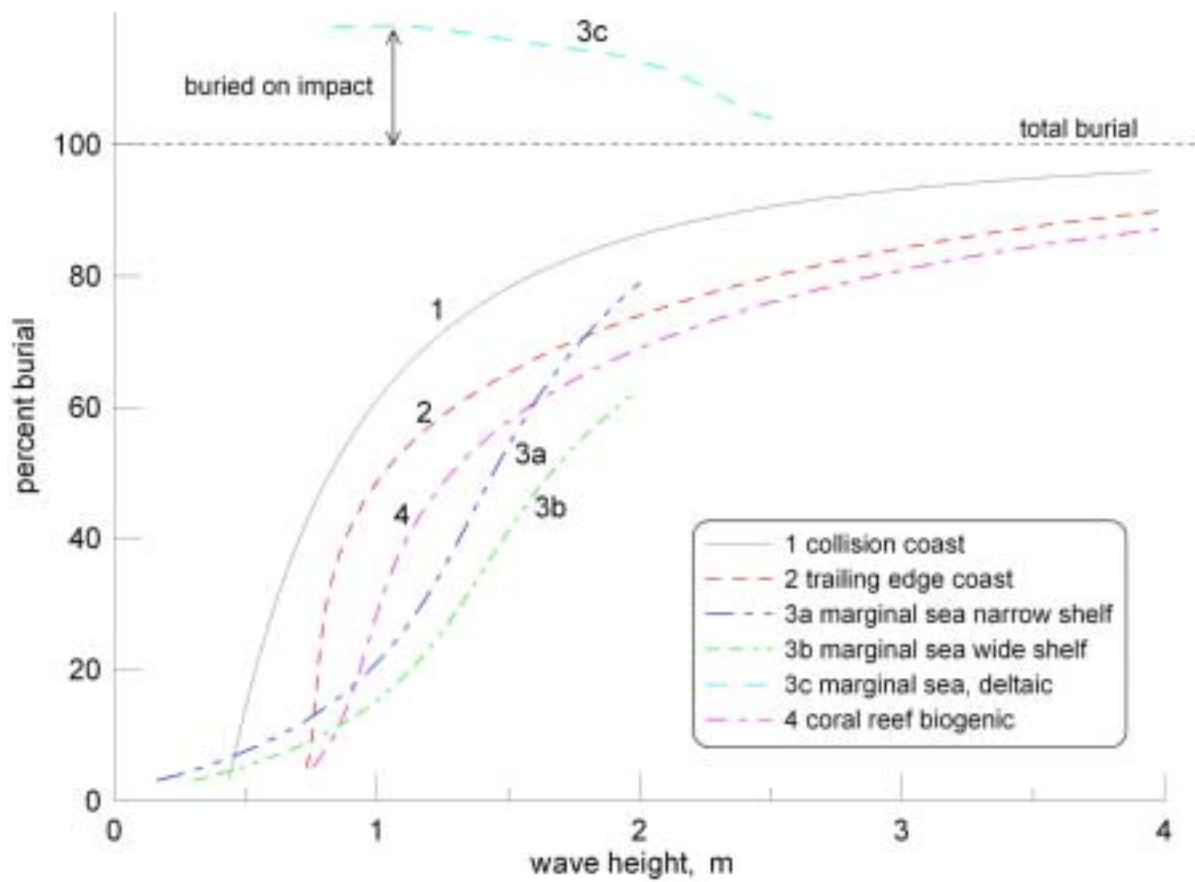
Figure 3. Predicted 30-day burial by waves of a MANTA mine in water depth of 7 m along various types of exposed coast. [from Inman and Jenkins, 2002]

Table 1. Rules of Thumb for Mine Burial Rates. [A]

Coastal Type	Morphology (Example)	Cylindrical Mines (MARK 52)				Truncated Cones (MANTA)			
		1 day	7 day	30 day	90 day	1 day	7 day	30 day	90 day
1. Collision	Narrow-Shelf Mountainous (California)	15%	35%	60%	80%	10%	25%	50%	65%
2. Trailing-Edge	Wide-Shelf Plains (Duck, NC)	12%	30%	50%	65%	8%	25%	45%	55%
3. Marginal Sea	a) Narrow-Shelf Mountainous (Korea)	10%	22%	40%	59%	6%	18%	38%	46%
	b) Wide-Shelf Plains (Corpus Christi)	5%	15%	19%	33%	3%	8%	12%	27%
	c) Deltaic Tideless (Mississippi)	75%	95%	100%	100%	70%	90%	100%	100%
	d) Deltaic Tidal (Bangladesh)	75%	85%	90%	100%	70%	80%	85%	100%
4. Arctic Form of Cryogenic	Wide-Shelf Plains Ice-push & gouging (Flaxman Barrier)	10% to 100%	10% to 100%	10% to 100%	10% to 100%	5% to 100%	5% to 100%	5% to 100%	5% to 100%
5. Coral Reef Form of Biogenic	Fringing Reef (Hawaii)	12%	28%	48%	60%	7%	20%	40%	50%

a Based on depth of 7 (mid VSW zone 3-12 m) and assumed mine specific gravity of 1.55 (from Inman and Jenkins, 2002).

IMPACT/APPLICATIONS

The geomorphic coastal classification system provides a rational framework for organizing world coastal diversity into a manageable number of discrete categories. This can provide a powerful management and decision making tool for resource agencies as well as for the mine warfare community. With respect to the latter, the mix of tactics that the VSW detachment is likely to use in a mine threat environment is strongly effected by many of the morphology and seabed properties organized by this system. Therefore our coastal classification system is a logical adjunct to the Mine Warfare Environmental Decision Aids Library (MEDAL) and could be used to systematize the databases within MEDAL and the doctrine around it.

TRANSITIONS

Three separate transitions are in progress: a) submission of a draft Mine Burial Primer (Inman and Jenkins, 2002), b) contribution to the   Mine Warfare Environmental Pocket Handbook,   and c) provide source code of the Vortex Lattice Model for the Ocean Atmosphere Model Library (OAML).

RELATED PROJECTS

The Vortex Model has been used as a design tool in the development of the VSW Neutralization Marker for the Marine Mammal Systems Branch, SPAWAR, Code D352. The model results for the VSW marker were used in the preparation of the Weapons System Explosive Safety Review Board, WSESRB documents. Sensitivity analysis of the model is being applied to evaluations of new lane marking concepts by the VSW/MCM detachment at PMS-EOD 7023. VORTEX will also be used to diagnose unexploded ordnance sites (UXO) under a CNO sponsored program directed by the Naval Facilities Engineering Service Center, Code ESC 51, Ocean Engineering, Pt. Hueneme, CA.

REFERENCES

Dill, R. F., 1958, The burial and scouring of ground mines on a sandy bottom, *U. S. Navy Electronics Laboratory*, San Diego, CA, Research Report NEL 861, 32 pp. (now unclassified)

Donohue, J. J. and L. E. Garrison, 1954, An evaluation of mine behavior observations in four test areas, *University of Rhode Island*, *Narragansett Marine Laboratory*, Reference 54-13, 79 pp.

Frazier, D. E. and C. E. Miller, 1955, Geological and engineering characteristics at mine behavior test sites, *University of Rhode Island, Narragansett Marine Laboratory*, Reference 55-16, 22 pp. + appen.

Garrison, L. E. and D. E. Frazier, 1954, Geology of mine behavior test areas (Addendum-Charlie Area), *Univ. Rhode Island*, Narragansett Marine Laboratory, Reference 54-21, 18 pp.

Inman, D. L. and C. E. Nordstrom, 1971, On the tectonic and morphologic classification of coasts, *Jour. of Geology*, v. 79, n. 1, p. 1-21.

Inman, D. L. and S. A. Jenkins, 1996, A chronology of ground mine studies and scour modeling in the vicinity of La Jolla, *University of California, San Diego*, Scripps Institution of Oceanography, SIO Reference Series 96-13, 26 pp.

Inman, D. L. and S. A. Jenkins, 2002, Scour and Burial of Bottom Mines A primer for fleet use, *University of California, San Diego*, Scripps Institution of Oceanography, SIO Reference Series 02-8, 47 pp. + appen A-B.

McMaster, R. L., L. E. Garrison and S. D. Hicks, 1955, Marine sedimentation project; mine behavior studies, *University of Rhode Island, Narragansett Marine Laboratory*, Reference 55-15, 38 pp. + 5 photos.

Salsman, G. G. and W. H. Tolbert, 1962, A summary of ground mine behavior characteristics, *U. S. Navy Mine Defense Laboratory* (now *Naval Coastal Systems Station*), Panama City, FL, 54 pp.

Salsman, G. G. and W. H. Tolbert, 1966, A seafloor burial experiment conducted off Panama City, FL, *U. S. Navy Mine Defense Laboratory* (now *Naval Coastal Systems Station*), Technical Note 75, 11 pp.

PUBLICATIONS

Inman, D. L. and S. A. Jenkins, 2001, Processes on narrow beaches with sandy foreshores and cobble berms, submitted to *California Shore and Beach Protection Association*, 8-10 November 2001, San Diego, CA, 2 pp.

Inman, D. L., in press 2002, Littoral cells, in M. Schwartz, ed., *Encyclopedia of Coastal Science*, Kluwer Academic Publishers, Dordrecht, Netherlands.

Inman, D. L. and S. A. Jenkins, 2002, Scour and Burial of Bottom Mines A primer for fleet use, *University of California, San Diego*, Scripps Institution of Oceanography, SIO Reference Series 02-8, 47 pp. + appen. A-B.

Inman, D. L. and S. A. Jenkins, in press 2002a, Climate patterns in the coastal zone, in M. Schwartz, ed., *Encyclopedia of Coastal Science*, Kluwer Academic Publishers, Dordrecht, Netherlands.

Inman, D. L. and S. A. Jenkins, in press 2002b, Accretion and erosion waves on beaches, in M. Schwartz, ed., *Encyclopedia of Coastal Science*, Kluwer Academic Publishers, Dordrecht, Netherlands.

Inman, D. L. and S. A. Jenkins, in press 2002c, Scour and burial of objects in shallow water, in M. Schwartz, ed., *Encyclopedia of Coastal Science*, Kluwer Academic Publishers, Dordrecht, Netherlands.

Jenkins, S. A. and D. L. Inman, submitted 2002, Thermodynamic solutions for ocean beach profiles, *Jour. Marine Res.*